Switched-mode power supply

The invention relates to a Switched-mode power supply
having a transformer, which has a primary winding and at
least one secondary winding, having a switching transistor
in series with the primary winding, and having a control
circuit for controlling an output voltage of the switched-
mode power supply. The control circuit in this case has an
oscillator, which presets a frequency at which the
switching transistor is switched on and off. Switched-mode
power supplies of this type are used, for example, in
televisions, video recorders and set-top boxes.

Appliances of this type normally use switched-mode power
supplies based on the flyback converter principle, which
produce a large number of stabilized supply voltages on the
output side. During operation, the control circuit
regulates one of the output voltages via a control loop.
This also results in the other output voltages from the
switched-mode power supply being stabilized. The control
circuit in this case controls the switching transistor by
means of a control signal such that the output voltage,
which is linked to the control loop, is kept constant by
means, for example, of pulse width modulation (PDM) or by
varying the frequency of the control signal for the
switching transistor.

Integrated circuits (ICs) are frequently used as the
control circuits, thus considerably simplifying the design
of a switched-mode power supply. Circuits of this type
normally contain control circuits, an oscillator, a driver
stage for directly driving a switching transistor, circuits
for the production of internal operating voltages, as well
as protection circuits.

A switched-mode power supply according to the prior art,
which has an integrated circuit IC1, is illustrated in
Figure 1. The switched-mode power supply uses a bridge

rectifier BR on the input side, by means of which an AC
voltage which is applied to a mains connection NA is
rectified. The rectified voltage U1 is smoothed by means of
an energy storage capacitor C1, and is applied to a primary
winding W1 of a transformer T1. The transformer T1 provides
mains isolation between the primary and secondary, and on
the primary side, has an auxiliary winding W2 for
production of an operating voltage VCC for the integrated
circuit IC1 and, on the secondary side, has windings W3 –
W5 for production of stabilized output voltages U3 – U5.
Rectified voltages are tapped off using rectifier means D1
– D3 across the windings W3 – W5, and are then smoothed by
means of low-pass filters LC1 – LC3.

A switching transistor Q1, in this exemplary embodiment a
MOSFET, whose output side is connected to earth via a
measurement resistor Rs, is connected in series with the
primary winding W1. The control input of the switching
transistor Q1 is connected to a driver stage DR of the
integrated circuit IC1, by means of which the switching
transistor Q1 is controlled. The switched-mode power supply
is in the form of a flyback converter, that is to say
energy is stored in the transformer T1 during operation
when the switching transistor Q1 is switched on, and is
transmitted to the windings W2 – W5 in the subsequent phase
in which the switching transistor Q1 is switched off.

This embodiment of the switched-mode power supply has a
control system on the primary side which operates via the
supply voltage VCC. The supply voltage VCC is produced
during operation by means of the auxiliary winding W2,
diodes D4, D5 and capacitors C2, C3. The supply voltage VCC
is applied to a connection 7 of the integrated circuit IC1,
so that the driver stage DR is supplied with voltage for
operation of the switching transistor Q1, and is applied to
a connection 8, via which the integrated circuit IC1
produces internal reference voltages as well as stabilized
supply voltages for operation of its circuits. The supply

voltage VCC is also applied via an RC filter RC1 and a
connection 2 to an error amplifier EA in the integrated
circuit IC1, providing regulation at a constant supply
voltage VCC. This also stabilizes the output voltages U3 –
V5, since the windings W2 – W5 are coupled to one another.

The integrated circuit IC1 can also be used for switched-
mode power supplies which are controlled on the secondary
side. A switched-mode power supply which is based on the
flyback converter principle and whose output voltage is
regulated on the secondary side is described, for example,
in US 4,876,636, which is hereby referred to. Regulation on
the secondary side results in better voltage stabilization.
The control loop in this case requires a transformer, for
example an optocoupler, a transmitter, for example an
optocoupler, via which the control signal is transmitted
from the secondary side to the primary side.

The integrated circuit IC1 has an oscillator O, whose
frequency can be adjusted by external circuitry by means of
a resistor R1 and a capacitor Ct at the connection 4. The
capacitor Ct is in this case charged via the resistor R1 by
means of a reference voltage Vref, which is applied to the
connection and is produced in the integrated circuit IC1.
When the voltage across the capacitor Ct reaches a specific
threshold value, this capacitor Ct is discharged via the
connection 4 of the integrated circuit IC1, so that a new
charging cycle can then take place.

The oscillator O presets the switching frequency for the
driver stage DR, and the pulse width of the driver signal
that is produced in the driver stage DR is varied via the
error amplifier EA and a downstream logic circuit LO, so
that the output voltages of the switched-mode power supply
are stabilized.

The switching frequency of the driver stage DR is in this
case half the switching frequency of the oscillator O. A

sawtooth pulse in this case presets the maximum time for which the switching transistor Q1 is switched on, and the subsequent sawtooth pulse sets the dead time, in which the switching transistor is switched off. This results in a maximum preset pulse width ratio of 50%, so that the transformer T1 is always demagnetized in the switched-off phase before the switching transistor Q1 is switched on again.

The switched-mode power supply also has a starting circuit AS, via which the integrated circuit IC1 is supplied with power once the switched-mode power supply has been switched on. In order to damp voltage spikes, a first damping network SN1 is connected on the input side to the switching transistor Q1 and is used to dissipate voltage spikes to the energy storage capacitor C1, and a second damping network SN2, which is connected in parallel with the switching transistor Q1.

The integrated circuit IC1 which has been described with reference to Figure 1 is in this exemplary embodiment a frequently used UC3845 Type, which is available, by way of example, from the company On Semiconductor (http://onsemi.com). Other controller ICs, such as MC33260, FA13843 and KA3843, also use external circuitry with a capacitor, by means of which the switching frequency of the switched-mode power supply can be adjusted.

The object of the present invention is to specify a switched-mode power supply of the type mentioned initially which has low losses.

This object is achieved for a switched-mode power supply by the features specified in Claim 1. Advantageous developments of the invention are specified in the dependent claims.

The switched-mode power supply according to the invention
has a transformer with a primary winding and two or more
secondary windings, a switching transistor in series with a
primary winding, a driver stage for controlling the
switching transistor and a control circuit for regulating
an output voltage. The control circuit in this case
contains an oscillator, which can be adjusted via a
connection and is coupled to a secondary winding in order
to determine the time at which the switching transistor is
switched on when an oscillation, in particular an
oscillation minimum, occurs on the secondary winding.

In one preferred exemplary embodiment, this is achieved by
means of a switching stage which passes on a supply voltage
to the connection when a sudden voltage change occurs on
the secondary winding at the time of an oscillation. This
results in the voltage at the connection going high, so
that the switching transistor is switched on via the
oscillator, and a new sawtooth pulse is triggered. Since a
voltage minimum likewise occurs at the current input of the
switching transistor when a voltage minimum occurs on the
secondary winding, the switching transistor is switched on
at a time at which the switched-on losses are low. This
makes it possible to considerably reduce the heat losses
that are produced in the switching transistor.

The switching stage is advantageously coupled to the driver
stage in order to block the switching stage when the
switching transistor is switched on by a positive voltage
from the driver stage. This prevents the sawtooth pulse
which defines the switching on of the switching transistor
from being disturbed by the switching stage but since this
sawtooth pulse determines the output power of the switched-
mode power supply via the pulse width ratio.

In one preferred exemplary embodiment, the connection is an
oscillator connection of an oscillator that is arranged in
an integrated circuit, and the supply voltage is a

reference voltage which is emitted at a second connection
of the integrated circuit and is applied to the oscillator
connection via an RC circuit. However, the invention is not
restricted to switched-mode power supplies with an
integrated circuit on the primary side as a controller
circuit, and can also be used for switched-mode power
supplies which have a discrete circuit on the primary side,
with an oscillator, a driver stage and a control circuit.

The invention will be explained in more detail in the
following text with reference, by way of example, to
schematic drawings, in which:

Figure 1   shows a switched-mode power supply with an
           integrated circuit on the primary side according
           to the prior art,
Figure 2   shows a switching stage for controlling the time
           at which the switching transistor is switched on,
Figure 3   shows voltage diagrams of the switched-mode power
           supply during operation at a relatively high
           power level, and
Figure 4   shows voltage diagrams of the switched-mode power
           supply during operation at a relatively low power
           level.

In Figure 2, a switching stage which has two transistors
T1, T2 is arranged between a connection 4 of an integrated
circuit and a secondary winding W6 of a transformer in the
switched-mode power supply. The integrated circuit
corresponds in particular to the circuit described in
Figure 1. The secondary winding W6 may be any desired
auxiliary winding on the primary side of the transformer
which is illustrated in Figure 1. The components of the
switched-mode power supply according to the invention,
which are not illustrated in Figure 2, likewise correspond,
for example, to the switched-mode power supply in Figure 1.
The same reference symbols are therefore used for identical
components. The switched-mode power supply may have control

on both the primary side and on the secondary side, and
preferably operates on the flyback converter principle. The
time at which the switching transistor Q1, which is
connected to the primary winding of the transformer, is
switched on is preset via the secondary winding W6 and the
switching stage, Figure 1.

The connection 4 is connected via a resistor R1 to a supply
voltage Vref which is applied to a connection 9, for
example to the connection 9 of the integrated circuit IC1
shown in Figure 1. The connection 4 is connected to earth
via a capacitor Ct. In consequence, the capacitor Ct is
periodically charged, as described above, by the supply
voltage which is applied to the connection 9. A first
transistor T1 and a resistor R2 with a low impedance are
connected in parallel with the resistor R1, so that the
resistor R1 is bridged when the transistor T1 is switched
on. The control input of the transistor T1 is connected to
the secondary winding W6 via a second transistor T2. The
transistor T1 is, in particular, a pnp transistor, and the
transistor T2 is an npn transistor, so that a positive
voltage switches on the transistor T2 and, in consequence,
the transistor T1.

A resistor R3 and a resistor R4 are connected in series
with the current input of the transistor T2 in order to set
voltages and in order to limit currents in the two
transistors. The resistor R3 is in this case connected to
the connection 9. A voltage divider formed by the resistors
R6, R7 and R8 is arranged between the transistor T2 in the
switching stage and the secondary winding W6, and is used
to defined a threshold value for switching on the
transistor T2. Furthermore, a capacitor C4 is connected
between the transistor T2 and the secondary winding W6, and
is used to limit the time of the voltage pulses in the
secondary winding W6.

The control input of the transistor T1 is connected via the
resistor R3 to the supply voltage Vref which is applied to
the connection 9, in this example 5 volts, and is coupled
via a diode D1 and a resistor R5 to an output 6 of the
driver stage, which controls the switching transistor Q1
which is connected to the primary winding of the
transformer. In this exemplary embodiment, this is the
output 6 of the integrated circuit IC1 illustrated in
Figure 1. This ensures that the transistor T1 is switched
off for as long as the switching transistor in the
switched-mode power supply is switched on. The transistor
T2 can thus not switch the transistor T1 on in this time
interval. However, if the driver voltage Ug applied to the
connection 6 is zero or is close to zero in order to switch
off the switching transistor Q1, the transistor T1 can be
switched on by the transistor T2.

The circuit operates as follows: when the switching
transistor Q1 is switched on, then the voltage Ug at the
connection 6 is high, for example approximately 20 volts.
This keeps the transistor T1 switched off via the diode D1.
When the switching transistor Q1 is subsequently switched
off, the voltage Ug at the connection 6 falls to about
0 volts. The diode D1 then becomes reverse-biased, so that
the transistor T1 is not influenced by the voltage Ug in
this time phase.

The voltage Ux on the secondary winding W6 is reversed when
the switching transistor Q1 is switched off, corresponding
to the voltage Ud at the current input of the switching
transistor Q1, and remains approximately constant for as
long as the energy which is stored in the transformer is
being transmitted to the secondary windings. Once the
magnetization of the transformer has been dissipated,
voltage oscillations occur on the windings of the
transformer as a result of capacitances which are connected
to the transformer, in particular as a result of the
capacitance in the snubber network SN2, see Figure 1.

The transistors T2 and T1 are thus switched on by a sudden
positive voltage change at the connection 10 of the winding
W6 at the time of the first oscillation, so that the
capacitor Ct is charged in a short time by the supply
voltage Vref up to the threshold value at which the
capacitor Ct is discharged again, and the integrated
circuit IC1 once again switches on the switching transistor
Q1 via the driver stage, and the next charging process of
the capacitor Ct takes place. Since the capacitor C4
applies only a short voltage surge to the base of the
transistor T2, the transistor T1 has already been switched
off when the capacitor Ct is being charged once again.

If the switched-mode power supply is operating with a
relatively high load, then the voltages Ux, Ud the voltage
across the capacitor Ct, U(Ct) and the voltage at the
collector of the transistor T2, U(T2) appear as is
illustrated in Figure 3. In this case, the switched-mode
power supply operates with a mains voltage NA of 230 volts,
and produces an output power of 23.8 watts. If the
switching transistor Q1 is switched on at a time t1, then
the voltage Ud is approximately zero and the voltage Ux
across the winding W6, which corresponds to a mirror image
of the voltage Ud across the primary winding W1, is
negative. The gate voltage Ug is high, for example
20 volts, in the time interval t1-t2 in which the switching
transistor Q1 is switched on, so that the voltage at the
collector of the transistor T2, U(T2) is likewise high,
since the diode D1 is forward-biased.

The switching transistor Q1 is switched off at the time t2,
so that both Ux and Ud rise steeply. As long as energy is
being transmitted to the secondary windings in the
switched-off phase, both the voltage Ud and the voltage Ux
remain high.

When the switching transistor Q1 is switched on, at the
time t1, a first sawtooth pulse SZ1, with a voltage U(Ct),
starts at the same time at the connection 4, since the
capacitor Ct is being charged. With the higher power of the
switched-mode power supply of 23.8 W, this ends before a
time t3, prior to which the transformer T1 transmits energy
to the secondary windings. The voltage U(T2) at the
collector of T2 falls gradually in the time period from t2
to t3, since the diode D1 is reverse-biased.

As mentioned above, the transformer discharge phase is
followed by an oscillation phase, until the time t3, in
which the voltages Ux and Ud fall. Owing to the inverted
polarity of the secondary winding W6, the voltage drop
produces a positive voltage pulse at the connection 10 of
the winding W6, so that the transistor T2 is then switched
on via the capacitor C4. The voltage U(T2) thus falls
steeply. In consequence, the capacitor Ct is charged very
quickly via the transistor T1 until the threshold value is
reached at a time t4, at which the capacitor Ct is
discharged again. This results in the switching transistor
Q1 being switched on again at a time t5. Thus, if the power
is relatively high, the time at which the switching
transistor Q1 is switched on occurs in the interval of the
sawtooth pulse SZ2, so that a new sawtooth pulse SZ3
starts, which corresponds to the pulse SZ1. The time t5
likewise corresponds to the time t1.

However, if the power is less, the first oscillation after
the discharge phase of the transformer T1 occurs, in the
time interval of the first sawtooth pulse SZ1, as is
illustrated in Figure 4. The output power of the switched-
mode power supply is in this case 12.2 watts. The phase in
which the switching transistor Q1 is switched on, the time
interval t1-t2 is somewhat shorter here, so that less
energy is stored in the transformer T1. The demagnetization
phase of the transformer T1, the time interval t2-t3, is in

consequence likewise shorter, and the time t3 therefore
still occurs within the first sawtooth pulse SZ1.

The voltage drop across the winding W6 after the time t3
once again results in a positive voltage pulse at the
connection 10, so that the transistor T2 is switched on, as
can be seen from the measurement curve CH4, U(T2) in Figure
4. This therefore ends the first sawtooth pulse SZ1 by the
capacitor Ct being charged up to the threshold value
voltage via the transistor T1, so that a second sawtooth
pulse SZ2' starts at a time T4'. However, since the
integrated circuit switches the switching transistor Q1 on
again after the second voltage pulse SZ2' or SZ2, as has
been explained above, then, when the power of a switched-
mode power supply is relatively low, this results in a long
quiescent phase of the transformer, the interval t4'-t5',
during which the capacitor Ct is charged only via the
resistor R1.

In consequence, when the output power is low, the switched-
mode power supply runs at only about half the switching
frequency of that used for a higher output power. Beyond a
certain output power level, the start of the oscillation
phase in this case occurs in the time interval of the first
sawtooth pulse SZ1, that is to say the switching frequency
is approximately halved below this threshold value. Thus,
when the power is low, the switching transistor Q1 is not
switched on by the switching stage in Figure 2, but by the
charging cycle t4' - t5' of the second sawtooth pulse SZ2'.

The circuit illustrated in Figure 2 results in the
integrated circuit IC1, which is in fact in the form of an
SMPS current mode controller for a fixed switching
frequency, operating at a variable switching frequency
corresponding to the output power. However, the switching
transistor cannot be switched on at a voltage minimum of an
oscillation which follows a discharge phase of a
transformer if the switching frequency is fixed. This is

made possible by the circuit illustrated in Figure 2. The
integrated circuit IC1 thus operates as a current mode PWM
controller with a low switching frequency when the
switched-mode power supply output power levels are low, and
operates as a quasi-resonant flyback converter, in which
the losses when the switching transistor Q1 is switched on
are reduced, when the output power levels are higher. A low
switching frequency with a low power is particularly
advantageous for low-loss standby operation.

The UC3845 integrated circuit is preferably used as the
integrated circuit IC1 for the switched-mode power supply
described here, although other SMPS controller ICs which,
in particular, have a connection for a capacitor Ct by
means of whose charging phase the switching frequency of
the integrated circuit is controlled may, however, likewise
be used. The invention can also be used for switched-mode
power supplies which have a control circuit with a discrete
component, with an oscillator for the switching transistor
which use a control circuit with discrete components and
with an oscillator for the switching transistor Q1, instead
of an integrator SMPS controller circuit. The invention can
be used not only for switched-mode power supplies which are
controlled on the secondary side, but also for switched-
mode power supplies which are controlled on the primary
side. In particular, the auxiliary winding W6 may also be
combined with the winding W2 in Figure 1, or may correspond
to it. Further modifications of the invention will be
evident to a person skilled in the art.